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13. ABSTRACT (Maximum 200 words)

This report summarizes research progress on the Duke University program to develop parallel (scalable) multi-level fast multipole algorithm (MLFMA) software for the modeling of electromagnetic scattering from general surface and subsurface targets.

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I. List of Manuscripts Submitted/Published under ARO Support

He JQ, Geng N, Nguyen L, Carin L, "Rigorous modeling of ultrawideband VHF scattering from tree trunks over flat and sloped terrain," IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, 39 (10): 2182-2193 OCT 2001

Geng N, Sullivan A, Carin L, "Fast multipole method for scattering from an arbitrary PEC target above or buried in a lossy half space," IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, 49 (5): 740-748 MAY 2001

Dong YT, Runkle PR, Carin L, Damarla R, Sullivan A, Ressler MA, Sichina J., "Multi-aspect detection of surface and shallow-buried unexploded ordnance via ultra-wideband synthetic aperture radar," IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, 39 (6): 1259-1270 JUN 2001

Xie YJ, He JQ, Sullivan A, Carin L, "A simple preconditioner for electric-field integral equations," MICROWAVE AND OPTICAL TECHNOLOGY LETTERS, 30 (1): 51-54 JUL 5 2001

Liu ZJ, Carin L, "Efficient evaluation of the half-space Green's function for fast-multipole scattering models," MICROWAVE AND OPTICAL TECHNOLOGY LETTERS, 29 (6): 388-392 JUN 20 2001

He JQ, Sullivan A, Carin L., "Multilevel fast multipole algorithm for three-dimensional dielectric targets in the vicinity of a lossy half space," MICROWAVE AND OPTICAL TECHNOLOGY LETTERS, 29 (2): 100-104 APR 20 2001

Liu ZJ; Jiangqi He; Yongjun Xie; Sullivan, A.; Carin, L.; "Multilevel fast multipole algorithm for general targets on a half-space interface," IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, 50 (12): 1838-1849, DEC 2002.

II. Scientific Personnel

Faculty: Lawrence Carin (PI) and John Board
Post-doc: John Pormann, Eric Jones and Zhijun Liu

III. Invention Reports

None.

IV. Scientific Progress and Accomplishments

Over the last several years the fast multipole model (FMM) has been employed to yield marked improvements in the computational power of electromagnetic models. In particular, the FMM has been applied to problems

that previously have been solved via techniques such as the method of moments (MoM). The MoM has been widely applied to the solution of electric, magnetic and combined-field surface-integral equations (EFIE, MFIE and CFIE, respectively). While the MoM is in principle applicable to targets of arbitrary shape and size, computational resources typically limit the range of problems for which it can be applied. In this context, if N unknowns are employed in the MoM formulation, the MoM solution requires order N^2 memory (RAM) to store the matrix equation, order N^2 computational complexity (CPU time) to fill the matrix, and order N^3 or PN^2 CPU time to solve the matrix equation (N^3 for an LU-decomposition solution and PN^2 for a conjugate-gradient (CG) type solution, where P represents the number of CG iterations). As the target size increases relative to wavelength, the commensurate increase in N substantially restricts the utility of MoM solutions. By contrast, the FMM integral-equation solution requires order $N^{3/2}$ memory and order $PN^{3/2}$ CPU time, while an MLFMA requires respectively order $N \log N$ and $PN \log N$. This implies that the FMM and MLFMA formulations allow consideration of scattering from targets of electrical size well beyond what is possible with the MoM.

The FMM and MLFMA have been applied to the analysis of scattering from electrically large and complex targets. However, these models have previously been applied primarily to scattering from free-space targets. In addition, there has been application of the FMM to problems involving planar conducting structures in thin stratified layers, through exploitation of an asymptotic form of the layered-medium Green's function. The FMM and MLFMA have also been extended to arbitrarily shaped conducting targets above or below a half space. Further, the MLFMA has recently been extended to the case of general dielectric targets in free space.

In the work pursued this past year, we combined algorithmic concepts considered separately in previous work - namely the half-space problem and scattering from dielectric targets - to develop an MLFMA for general dielectric targets above or below a lossy half space. For the "near" MLFMA terms the complete dyadic half-space Green's function is evaluated rigorously via the complex-image technique, for electric and magnetic current sources. An approximate asymptotic form of the Green's function is applied for the "far" MLFMA interactions, although we have demonstrated that this approximate formulation yields highly accurate results, with computational efficiency. Scattering from the dielectric target is treated using a traditional formulation employing electric and magnetic surface currents, with a solution based on the widely used Rao, Wilton, Glisson (RWG) basis functions. The MLFMA formulation pursued here, for general dielectric targets in the presence of a half space, has application to a large class of problems. For example, for land mines in the presence of a dielectric rough surface, and/or mines in the presence of foliage. The MLFMA pursued here is applicable to the analysis of scattering from electrically large dielectric scatterers, above a lossy, dispersive soil. Moreover, one is also interested in scattering from general subsurface targets, such as plastic land mines at high radar frequencies, for which the land-mine target can become electrically large.

V. Technology Transfer

The MLFMA models developed under this program have been delivered to Dr. Anders Sullivan at the Army Research Laboratory, Adelphi, MD.